13.—Middle Holocene marine molluscs from near Guildford, Western Australia, and evidence for climatic change

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Abstract

Thirty one species of fossil molluscs are reported from a subsurface Middle Holocene deposit near Guildford, Western Australia, 26 km upstream from the mouth of the Swan Estuary. A radiocarbon age of 6660 ± 120 yr BP (shell carbonate) indicates that the fauna lived near the end of the Flandrian transgression. In the light of their modern distributions, the fossils indicate that in Middle Holocene time, the Swan Estuary was a hydrologically stable arm of the sea, which experienced considerably less winter flooding than at present. A period of regional aridity is indicated, continuing on to some time after 4500 yr BP.

Introduction

During 1969-70, the Western Australian Public Works Department was engaged in channel clearing and deepening along a part of the estuary of the Swan River below Guildford (lat. 31° 54′ S, long. 115° 58′ E) and about 26 km upstream from the mouth at Fremantle. The area dredged was about 1 000 m long by 45 m wide, on either side of but mainly below the Helena River confluence (Fig. 1). Spoil was pumped ashore and discharged from a steel pipe line about 0.7 km away on the flood-plain of the Helena River adjacent to Great Eastern Highway and the Guildford State Primary School to provide for an extension of the school grounds.

As discharged from the pipe, the spoil comprised a coarse, greyish-brown, poorly sorted quartz sand with a high proportion of angular grains, together with fragments of granitic rock and feldspar, mica flakes and occasional small ferruginous nodules. These components suggest a recent origin from the Precambrian rocks and associated laterite of the Darling Range. In addition, scattered sparsely within the spoil, were occasional mollusc shells and small pieces of soft, grey, calcareous, sandy siltstone, mostly shell-bearing. Many shells however were free of sediment (referred to below as "clean") and a large proportion were also freshly broken or abraded; likewise the pieces of siltstone showed evidence of heavy abrasion as a result of their passage along the discharge pipe.

The stratigraphic relationship of the elements of the spoil-pile has not been observed directly but according to the Public Works Department the modern channel bed is composed of "coarse sand". Dredging removed from 0.3 to 2.1 m of the substrate, and the resulting channel bed had a reduced level ranging from 4.4 to 5.6 m below Australian Height Datum (equivalent to mean sea level). It seems probable that the shell-bearing siltstone came from low in the cut beneath the channel sand and, from its relative scarcity in the spoil, was either of no great thickness or was only slightly or intermittently penetrated by the dredge.

Collections of shells from the spoil-pile were made firstly by Mrs. H. E. Merrrifield in December 1969, and subsequently by the writer in January and February 1970 and again in February 1971. The specimens have been accessed into the collection of the Western Australian Museum and provide the basis of this report. Most are in fresh, unweathered condition and, apart from some recent breakage, are well preserved.

The fossil species

Altogether, 35 species of molluscs, as well as crustaceans, polychaete tubes and a bryozoan were represented in the material collected. Identifications are available only for the molluscs, of which 18 species were represented by specimens directly associated with the grey siltstone. The remaining 17 species are considered to comprise two groups, the larger, of 13 species, being mostly fragmentary shells which evidently had been washed and tumbled free of sediment in passage along the pipe. The lesser group of 4 species comprised the bivalves *Westralunio carteri* Iredale, *Xenostrobus securis* (Lamarck) and *Anticorbula amara* (Laseron) and the gastropod *Plotiopsis australis* (I. and H. C. Lea). With the exception of the first-mentioned, these are permanent inhabitants of the Swan near Guildford (Chalmer *et al.* 1976); *W. carteri* inhabits freshwater tributaries such as the Helena River and Bennett Brook. The shells of these 4 species are believed to be associated with the sand of the channel substrate rather than the calcareous siltstone and to represent the modern fauna at Guildford and upstream. Likewise, specimens of the flat-backed crab *Halicarcinus australis* (Haswell) (WAM 70.138), collected from the spoil-pile, are considered to be modern.

With this adjustment, the fossil molluscs are found to comprise 31 species, of which 16 are bivalves and 15 gastropods. In the following discussion, subdivisions (Lower, Middle and Upper) of the Swan Estuary and modern distributions within the estuary are from Chalmer *et al.* (1976). Other non-estuarine records are from the collection of modern molluscs of the Western Australian Museum.

Bivalves

Mytilidae

Musculus sp. cf. *M. nanulus* Thiele. Material: numerous specimens of mature size, mostly disarticulated valves embedded in grey siltstone;

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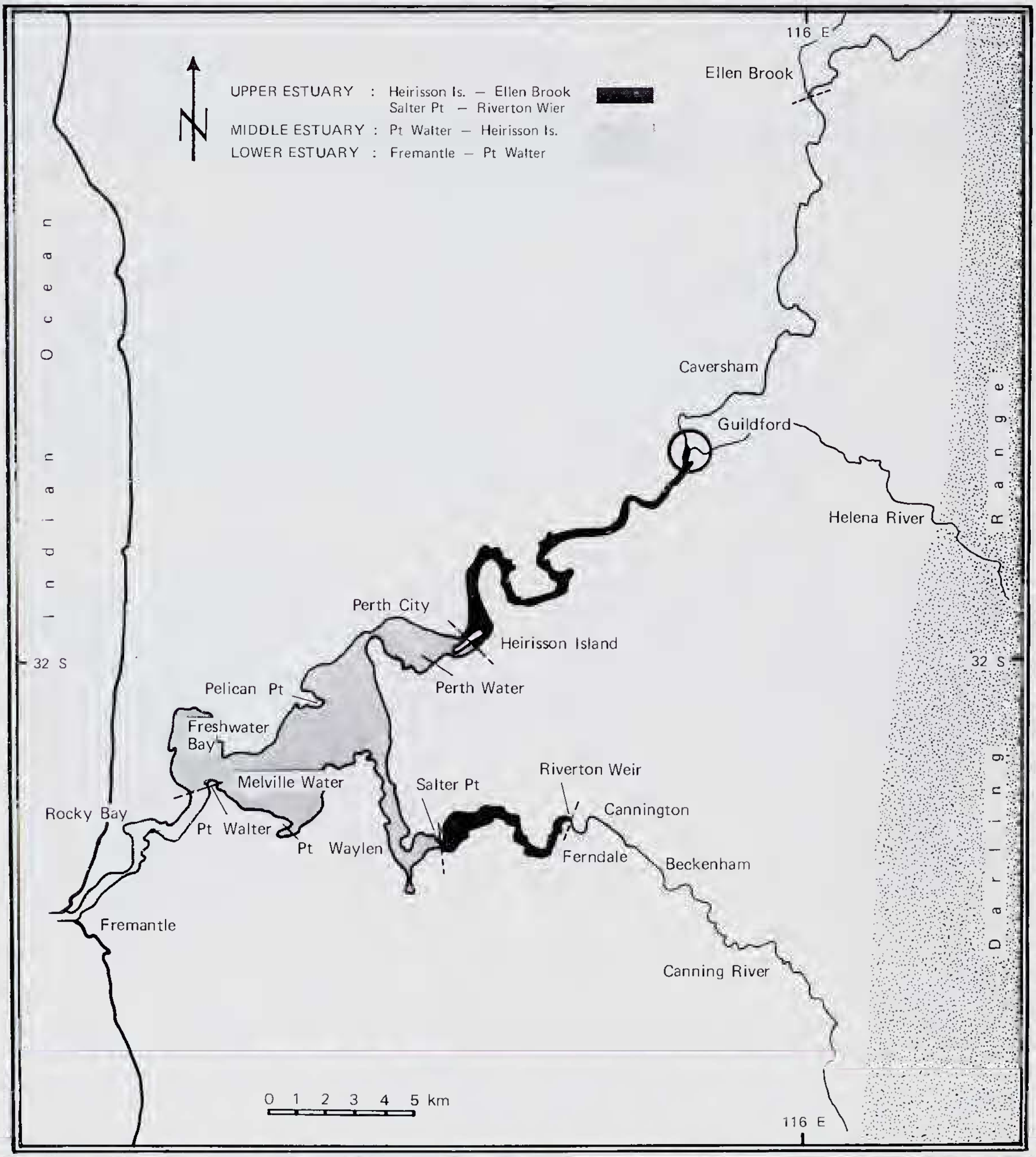

Figure 1.—Swan River estuary. Localities mentioned in text. Fossil site circled.

two "clean" singles. WAM 70.66, 70.73, 70.110, 70.111, 70.143. The relationship of this to Thiele's species, described from Shark Bay (Thiele 1930) is not clear. Guildford specimens have 35-40 ribs on the posterior slope and are up to 8 mm long. Habitat unknown but probably byssally attached to seagrasses, etc. This species now lives periodically within the Lower Estuary.

Pectinidae

Pecten modestus Reeve. Material: a substantially complete left valve and a fragment of a right, both "clean". WAM 70.69, 70.112. The latter measures 55 x 61 mm and is about $\frac{3}{4}$ mature size. Modern geographic range: southern Australia north to Shark Bay. Not recorded living from the Swan Estuary. An epifaunal species with some swimming ability.

Ostreidae

Ostrea angasi Sowerby. Material: an articulated pair of mature size, filled with grey siltstone; two small singles embedded in siltstone; eight "clean" singles, mostly mature, four attached in a cluster and with adherent *Chama* valves; the largest 11 x 9 cm (slightly damaged). WAM 70.67, 70.68, 70.70, 70.113, 71.483. Modern geographic range: southern Australia, principally in estuaries (Macpherson and Gabriel 1962) but apparently not now living north of Cape Leeuwin. An epifaunal species, attached to stones, other shells, etc. below low water mark.

Chamidae

Chama ruderalis Lamarck. Material: three articulated pairs and five lefts embedded in grey siltstone; 13 left valves attached to oyster and other shells; five right and three left singles, all "clean". Most specimens are comparable in size with local modern marine specimens. WAM 70.70, 70.113, 70.115, 71.483. Modern geographic range: South Australia, southern Western Australia (Cotton 1961), north to about Fremantle. Now lives probably permanently in the Lower Estuary. A sessile, epifaunal species, attached to firm substrates at or below low water mark.

Cardiidae

Laevicardium (Fulvia) apertum (Bruguière). Material: two articulated pairs and three single valves embedded in grey siltstone; one fragment with adherent *Chama* valves; two "clean" fragments. Specimens are comparable in size with local marine shells. WAM 70.70, 70.71, 70.72, 70.73, 70.111. Modern geographic range: Indo-SW Pacific; in Western Australia south to Cockburn Sound (common) and Geographe Bay (rare). Now lives periodically in the Lower Estuary and part of the Middle Estuary (in the vicinity of Pt Walter). An infaunal burrower in sandy to muddy substrates.

Laevicardium (Fulvia) tenuicostatum (Lamarck). Material: one small left valve and two fragments from larger valves, all "clean". WAM 70.74. Modern geographic range: southern Australia, north to about Fremantle; not recorded living from the Swan Estuary. An infaunal burrower in sandy to silty substrates.

Tellinidae

Tellina (Tellinangulus) sp. Material: two single valves, one with a little adherent grey calcareous sediment; the larger 5 mm long. WAM 70.83, 70.146. Modern geographic range: not known. Now common in the deeper parts of Cockburn Sound; lives periodically within the Lower Estuary. Probably an infaunal burrower.

Tellina (Pinguitellina) sp. Material: a "clean" left valve of mature size (14 x 10 x 3 mm). WAM 70.121. Modern geographic range: Cockburn Sound to Shark Bay; now lives probably permanently within the Lower Estuary. Probably an infaunal burrower.

Tellina sp. Material: 21 "clean" valves, the largest 24 x 15 x 3 mm and comparable in size to local modern marine specimens. WAM 70.81, 70.120, 70.145. Modern geographic range: not known. Now common in the sea near Fremantle, particularly Cockburn Sound, and lives periodically within the Lower Estuary. Of uncertain subgenus, this is an infaunal burrower in fine substrates.

Psammobiidae

Sanguinolaria (Psammotellina) biradiata (Wood). Material: a fragmentary left valve of medium size. WAM 70.119. Modern geographic range: southern Australia north to about Fremantle; lives permanently within the Lower Estuary. A deep burrower in sandy to muddy substrates.

Veneridae

Dosinia (Pectunculus) sculpta (Hanley). Material: one juvenile, articulated pair embedded in grey siltstone; three left and three right valves, all "clean", the largest 37 x 40 x 9 mm. WAM 70.75, 71.483. Modern geographic range: northern and Western Australia, south to about Cockburn Sound; living periodically within the Lower Estuary. A burrowing species in fine substrates.

Circe sulcata Gray. Material: two articulated pairs containing grey siltstone and a single embedded in the same; one left valve with adherent siltstone; seventeen "clean" singles, the largest 29 x 31 x 7 mm. WAM 70.76, 70.77, 70.116, 70.144, 70.2719. Modern geographic range: Indo-SW Pacific; in Western Australia, south to Albany; living periodically within the Lower and Middle Estuaries. A burrowing species in fine substrates; living specimens sometimes found on the surface of the substrate.

Paphia (Callistotapes) crassisulca (Lamarck). Material: one broken left valve with adherent grey siltstone; a complete juvenile right and part of an adult left valve, both "clean"; a shell of *Ostrea angasi* with the external impression of a mature *P. (C.) crassisulca* on the lower valve. WAM 70.68, 70.78, 70.79. Shells of this species were common in the original collections and most were used for radiocarbon dating. Modern geographic range: Indian Ocean, northern Australia (Fischer-Piette and Métivier 1971); in Western Australia south to Cockburn Sound (common) and Cape Naturaliste (rare); probably living permanently in the channel of the Lower Estuary. A burrowing species in fine substrates.

Irus irus (Linnaeus). Material: two "clean" single valves and a fragmentary single extracted from a cavity of a piece of teredine-bored wood. WAM 70.117, 70.118. Modern geographic range: E. Atlantic, Mediterranean, Indo-W. Pacific (Fischer-Piette and Métivier 1971), Western Australia south to Cockburn Sound; not recorded living from the modern Swan Estuary. Inhabits crevices of rocks, shells, wood, etc.

Hiatellidae

Hiatella australis Lamarck. Material: four articulated pairs and three singles embedded in siltstone; eleven "clean" singles, the largest 13 x 5 mm, which is small compared with marine specimens. WAM 70.66, 70.68, 70.71, 70.84, 70.111, 70.123, 70.144, 71.483. Modern geographic range: Australia generally (Macpherson and Gabriel 1962); living periodically within the Lower Estuary. A sessile species inhabiting crevices of rocks, shells, etc.

Pholadidae

Pholas sp. cf. *P. australasiae* Sowerby. Material: a posterior fragment of a "clean" medium-sized right valve, probably of this species. WAM 70.82. Modern geographic range: Australia generally (Macpherson and Gabriel 1962); not recorded living from the modern Swan Estuary. A sedentary species confined to burrows near low water mark; often collected near the mouths of estuaries.

Gastropods

Trochidae

Monilea callifera (Lamarck). Material: two shells, one filled with siltstone, the other "clean". The larger shell measures 12 x 9 mm, about half mature size. WAM 70.124, 70.139. Modern geographic range: Indo-SW Pacific; in Western Australia, south to Safety Bay; living periodically in the Lower Estuary. A herbivore associated with seagrasses in marine bays.

Cyclostrematidae

Elachorbis tatei (Angas). Material: four shells, one embedded in siltstone and three "clean", the largest 3 mm in diameter. WAM 70.86, 70.111. Modern geographic range: South and Western Australia north to Shark Bay; living periodically within the Lower Estuary. A herbivore associated with seagrass and algal growth in sheltered waters.

Diastomatidae

Obtortio (Alabina) sp. Material: five shells embedded in siltstone and 25 "clean" shells, generally of mature size. WAM 70.71, 70.87, 70.111, 70.126, 70.143. Modern geographic range: southwestern Australia, Albany to Shark Bay; living periodically within the Lower Estuary. Associated with fine substrates in sheltered waters. This may be the species listed by Thiele (1930) as *Finella pupoides* A. Adams, from Shark Bay and Warnbro Sound.

Cerithiidae

Alaba fragilis (Thiele). Material: three shells embedded in siltstone; two "clean" shells, the largest 6 mm high. WAM 70.88, 70.111, 70.127. Modern geographic range: not known. Lives in Cockburn Sound and permanently in the Lower Swan Estuary, being described originally from Freshwater Bay (Thiele 1930). A herbivore associated with algal and seagrass beds in sheltered waters.

Epitoniidae

Epitonium sp. cf. *E. imperiale* (Sowerby). Material: two "clean" shells, the larger 9 mm high, which may be either juveniles of *E. imperiale* or another, closely related species. WAM 70.140. Modern geographic range: *E. imperiale* occurs in the Indo-SW Pacific and in Western Australia, south to Cape Naturaliste (Wilson and Gillett 1971). In Cockburn Sound it is believed to be associated commensally with the anemone *Radianthus concinnata* Lager (S. Slack-Smith, pers. comm., April 1975). Modern shells apparently conspecific with the Guildford specimens, are occasionally collected in the Lower Estuary of the Swan, where they may be living periodically.

Naticidae

Polinices (Conuber) conicus (Lamarck). Material: five "clean" shells, the largest damaged but originally about 4 cm high. WAM 70.89, 70.128. Modern geographic range: Australia generally; not recorded living from the Swan Estuary. An active, infaunal predator on bivalves, etc. A gastropod drill-hole of the bevelled type attributed to the Naticidae by Bromley (in Crimes and Harper 1970) was observed on a specimen of *Dosinia sculpta* (WAM 70.75c).

Nassariidae

Nassarius rufulus (Kiener). Material: one "clean" fragment from a shell probably about 17 mm high. WAM 70.131. Modern geographic range: south-western Australia, Albany to Geraldton (Wilson and Gillett 1971); not recorded living from the Swan Estuary. An infaunal scavenger/predator in shallow marine habitats.

Nassarius pauperatus (Lamarck). Material: 32 shells, one filled with grey sandy siltstone; several incomplete. The largest shell measures 14 x 8 mm. WAM 70.129, 70.130, 70.141. Modern geographic range: southern Australia; in Western Australia north to Geraldton (Wilson and Gillett 1971); permanently living in the Lower and Middle Estuaries. An infaunal scavenger/predator, common in estuaries and marine bays.

Nassarius pyrrhus (Menke). Material: a fragmentary shell, lacking the spire, when intact about 10 mm high. WAM 74.895. Modern geographic range: southern Australia, Victoria to Fremantle (Hodgkin *et al.* 1966); living periodically within the Lower Estuary. A scavenger/predator common in estuaries and marine bays.

Pyramidellidae

Turbonilla (Chemnitzia) mariae Tenison Woods. Material: four "clean" shells. WAM 70.92. Modern geographic range: southern Australia (Cotton 1959); not recorded living from the Swan Estuary. An ectoparasite.

Turbonilla (Chemnitzia) sp. Material: one shell embedded in and another extracted from siltstone; one "clean" shell. WAM 70.134, 71.484, 75.821. Distinguished from the preceding by having more ribs per whorl and a larger protoconch perched atop poorly ribbed apical whorls; akin to *T. (C.) macleayana* Tenison Woods (R. Burn, pers. comm., Jan. 1975). Modern geographic range: unknown; not recorded living from the Swan Estuary. An ectoparasite.

Agatha simplex (Angas). Material: one shell extracted from a piece of grey siltstone and one "clean" shell. WAM 70.91, 74.1123. Modern geographic range: Queensland—southern Australia—north western Australia (Cotton 1959); not recorded living from the Swan Estuary. An ectoparasite.

Atysidae

Liloa brevis (Quoy and Gaimard). Material: six "clean" shells, the largest 6.5 mm high. WAM 70.90, 70.132, 70.142. Modern geographic range: southern Australia, New South Wales to Fremantle (Hodgkin *et al.* 1966); living periodically within the Lower Estuary. A herbivore associated with seagrasses in sheltered waters.

Retusidae

Retusa sp. A. Material: one shell embedded in grey siltstone. WAM 70.111. A thin-shelled species, differing in shape from *Retusa* sp. B. Modern geographic range: not known, but living at least periodically in the Lower Estuary (R. Burn, pers. comm., Jan. 1975). An infaunal carnivore on foraminifers and/or small molluscs.

Retusa sp. B. Material: one juvenile shell, extracted from a piece of grey siltstone. WAM 70.133. Modern geographic range: not known. Close to *R. pygmaea* (A. Adams), a southern Australian species (R. Burn, pers. comm., Jan. 1975). An infaunal carnivore on foraminifers and/or small molluscs.

Age and correlation

One of the more common species in the fossil material was the bivalve *Paphia crassisulca*, a robust, medium-sized clam, mature specimens of which measure from 2 to 3 mm through each valve. A comparative X-ray diffraction examination of a Guildford fossil (WAM 70.79b) of *P. crassisulca* and a modern specimen of the same species from Cockburn Sound near Fremantle showed that each was composed of aragonite; no calcite was detected in either specimen and no significant compositional or crystallographic differences were noted between the two (M. Price and D. Burns, Government Chemical Laboratories, pers. comm., Dec. 1975). Thus the material has not been involved in any detectable carbonate exchange and is suitable for carbon-14 dating.

A 200 g sample of these shells from Guildford was submitted for radiocarbon dating and a C^{14} age of 6660 ± 120 yr BP (GaK 2874) was determined (Kigoshi *et al.* 1973). From this it is concluded that the deposit of siltstone presumed to underlie the modern channel sand at the dredged site was formed during Middle Holocene time and near the end of the Flandrian or last major glacio-eustatic transgression of the sea (Mörner 1976). There is a general agreement between the age and estimated position of the Guildford deposit (about 5 m below datum) and data presented by Thom and Chappell (1975) from Australian sources. However no precise sea level can be deduced from the evidence available at Guildford.

Shell beds of similar composition and age occur in the Swan Estuary at Heirisson Island, Perth and Melville Waters, etc., and have been discussed by Maitland (1919, p. 53), Reath (1925), Serventy (1955, p. 71) and Clarke *et al.* (1967, p. 136). The Guildford occurrence is more distant from the sea than any of these. Other shell beds from excavations at Cannington, Beckenham and Ferndale, on the Canning River well upstream from the modern broadwaters of the estuary, are under study by the writer. These contain mollusc faunas similar to that from Guildford and are considered to be of approximately similar age.

The Guildford Mid-Holocene molluscs differ markedly in species and preservation from those of the Caversham clay pits of Brisbane and Wunderlich Pty, located some 3 km to the north (Fairbridge 1954). Lying several metres above Datum, the Caversham deposit contains the bivalves *Anadara trapezia* (Deshayes), *Mactra (Diaphoromactra) versicolor* Tate and other species unknown in the Guildford fauna. The Caversham deposit is noticeably weathered and evidently is of Pleistocene age (Noakes *et al.* 1967), probably deriving from the high sea levels of the Last Interglacial, approximately 100 000 yr ago (Broecker and van Donk 1970).

Comparison of fossil and modern faunas

The present Swan Estuary experiences a well defined, two phase, annual hydrologic cycle, which derives from the Mediterranean type climate of the region (Spencer 1956; Wilson 1968, 1969). Reliable, intense winter rainfall results in strong river discharge into the estuary, leading to a sharp drop in salinity and temperature, stratification and deoxygenation of the water body; during each summer drought, this is replaced by marine circulation induced by a weak tidal oscillation. This marked seasonal contrast in the estuarine environment is reflected in the distribution of the permanent benthic fauna, the species diversity of which declines sharply with distance from the sea. Thus Chalmer *et al.* (1976) report 23 mollusc species living permanently in the Lower Estuary, 10 in the Middle Estuary and only 6 in the Upper Estuary; only 4 species are known to live permanently in the Upper Estuary near Guildford.

An analysis of the Guildford molluscs is presented in Table 1. They are grouped into three categories of "permanently resident", "periodically resident" and "not recorded" in the present day Swan Estuary. Of the 31 species represented, only 7 are believed to still inhabit the estuary permanently and 6 of these appear to be confined to the Lower Estuary; the seventh ranges further upstream into parts of the Middle Estuary. A second group of 13 species lives from time to time in the Lower Estuary, when conditions are temporarily favourable (i.e., during periods of low river discharge), but appears to be unable to live permanently in any part of the modern estuary, dying out in times of high winter discharge. The remaining 11 species have not been recorded from the modern estuary as either periodic or permanent inhabitants; all are of marine affinity and are either known or presumed to occur in marine environments in south-western Australia. Chalmer *et al.* (1976) recorded 6 mollusc species, all permanent residents of the Middle Estuary of the Swan, which appeared to be more abundant in estuarine rather than normal marine environments. Of these 6, only 1, *Nassarius pauperatus*, is represented among the Guildford fossils. The modern upstream limit of this species is at about Pelican Point (Fig. 1). The same workers further recognized a group of 5 exclusively estuarine mollusc species characteristic of the Middle and Upper Estuaries, none of which is represented among the Guildford fossils.

The differences in range and composition noted between the Guildford fossil assemblage and the modern estuary fauna show that there has been a general contraction seaward by all of the former (grouping of species) since the Middle Holocene, indicating that a substantial environmental change has affected the estuary since that time. The fossils include filter-feeding infaunal and epifaunal bivalves and herbivorous, scavenging, carnivorous and ectoparasitic gastropods. Other groups probably also present by inference were seagrasses, one or more actinarians and other host-species, such as sabellid worms, for a suite of pyramidellid snails. Most species are represented by specimens of average-mature size and the fauna has a balanced diversity consistent with relatively stable, near-normal marine salinity in a marginal, sheltered, gulf environment. The Guildford fossils probably represent a life assemblage or biocoenosis (Schafer 1972). If so, the evidence obtained is not compatible with modern levels of river dis-

Table 1

Mollusc species from Guildford grouped according to their modern occurrences in the Swan Estuary; comparative data from Chalmer et al. (1976) and R. Burn (pers. comm., April 1975).

(i) Probable permanent inhabitants of the Lower Estuary (7 species). Asterisk denotes species probably also living permanently in part of the Middle Estuary.

Chama ruderalis	*Paphia (Callistotapes) crassisulca*
Tellina (Pinguitellina) sp.	*Alaba fragilis*
Tellina sp.	*Nassarius pauperatus**
Sanguinolaria (Psammotellina) biradiata	

(ii) Periodic inhabitants of the Lower Estuary (13 species). Asterisk denotes species which may range periodically into the lower part of the Middle Estuary.

Musculus sp. cf. *M. nanulus*	*Elachorbis tatei*
*Laevicardium (Fulvia) apertum**	*Obtortio (Alabina)* sp.
Tellina (Tellinangulus) sp.	*Epitonium* sp. cf. *E. imperiale*
Dosinia (Pectunculus) sculpta	*Nassarius pyrrhus*
*Circe sulcata**	*Liloa brevis*
Hiatella australis	*Retusa* sp. A (advice from R. Burn)
Monilea callifera	

(iii) Not recorded in the modern estuary fauna (11 species).

Pecten modestus	*Nassarius rufulus*
Ostrea angasi	*Turbonilla (Chemnitzia) mariae*
Laevicardium (Fulvia) tenuicostatum	*Turbonilla (Chemnitzia)* sp.
Irus irus	*Agatha simplex*
Pholas australasiae	*Retusa* sp. B (advice from R. Burn)
Polinices (Conuber) conicus	

charge and indicates that a qualitatively different hydrologic regime prevailed in the estuary during the Middle Holocene.

Hydrologic regime

From Fremantle Harbour to Rocky Bay, the Swan Estuary in its lowermost, inlet section is partly obstructed by an extensive sand-sill, which acts as a barrier to the free circulation of sea water into the Middle Estuary and beyond (Chalmer *et al.* 1976). Dredge spoil from this sill has been found to contain a high proportion of fresh mollusc shell and other biogenic carbonate and appears to be of marine origin (G.W.K., unpublished data). The Guildford fossil deposit was formed near the culmination of the transgressive phase of the Holocene depositional cycle, at which time the estuary was rather deeper than is now the case. This was particularly so of the lower reaches, as a consequence of extensive downcutting by the Swan during the low sea levels of the late Pleistocene (Churchill 1959). The presence of a deep oceanic connection extending through the Lower Estuary and most if not all of the Middle Estuary would have greatly enhanced marine influence throughout the entire estuary but, in conjunction with modern levels of stream discharge, could not, of itself, account for the presence of marine molluscs at Guildford.

The marine component of the estuarine Swan environment was clearly stronger than at present during the Middle Holocene but the character of the complementary fluviatile element needs to be considered also. Of the various parameters of river discharge, the two most relevant appear to be volume and concentration (i.e. seasonality). A volume of discharge equal to or greater than present levels is ruled out by the fossil and lithologic evidence. The site is located around the Swan-Helena confluence, the latter now being a major freshwater tributary. Geological maps of the district (Low and Lake 1971) suggest that there have been no more than minor changes in the position of the confluence during the Holocene. The presence at Guildford of marine species, such as *Pecten modestus, Laevicardium tenuicostatum, Polinices conicus* and *Nassarius rufulus* is highly significant. These species are now living in the sea around Fremantle but apparently are unable to live anywhere within the Swan Estuary under prevailing conditions. Their presence as fossils in the Swan near the Helena confluence is incompatible with active discharge from that tributary, whether this was seasonal (as now) or continuous. The same reasoning applies with almost equal force to other species in the fossil assemblage, for example, *Chama ruderalis, Laevicardium apertum, Sanguinolaria biradiata, Circe sulcata, Paphia crassisulca* and *Epitonium* sp. cf. *E. imperiale.* These are now able to live either permanently or temporarily in the estuary within a few km of the sea, but nowhere within 20 km of Guildford.

The most likely reconstruction of the hydrologic situation in the Middle Holocene Swan would seem to require a substantially reduced volume of river discharge throughout the entire drainage basin. Under such conditions, the importance of seasonality of discharge would tend to diminish, even to the point of becoming difficult to recognize and assess. The indications are, however, that both discharge volume and seasonality were much lower than at present and, hence, that the climate was relatively dry.

Climatic change in the Middle Holocene

The time of onset of this postulated dry episode pre-dates 6700 yr BP but is otherwise unknown. Radiocarbon dates from an undisturbed, partly emergent shell bed at Point Waylen, Melville Water, may help to clarify an upper, terminal date. Mollusc shell carbonate from 10-20 cm above and 60-80 cm below Datum have produced ages of 4500 ± 100 yr BP (SUA 339) and 5940 ± 110 yr BP (SUA 341) respectively (Gillespie and Temple 1976). Faunal studies in progress on the Point Waylen deposit indicate that the mollusc assemblage, with over 60 species, is highly diverse and, like the Guildford material, lived under hydrologically stable, marine-gulf conditions. The fossil assemblages from Guildford and Point Waylen are similar and lead to the tentative conclusion that the modern hydrologic seasonality of the Swan Estuary did not develop until some time after 4500 radiocarbon yr BP.

Late Quaternary climates in south-western Australia have received little detailed study and interpretations of evidence obtained by Lundelius (1960) and Churchill (1968) have not supported the concept of a relatively dry Mid-Holocene in the region. Churchill (1960) envisaged a Mid-Holocene extinction of a "*Eucalyptus-Casuarina* woodland, *Xanthorrhoea, Macrozamia* and possibly *Banksia* and *Agonis* scrubs" on Rottnest Island, seeing this as a consequence of "a marine transgression to at least 9 feet above present sea level in 2000 B.C.", corresponding to the Older Peron strandline of Fairbridge (1950). Such a post-Pleistocene stand of the sea has not won general acceptance (Mörner 1976; Thom and Chappell 1975) and is not supported by the writer's observations of the Holocene shell beds of the Swan Estuary, located within 50 km of Point Peron. These suggest that the maximum Mid-Holocene transgression in this region stood little, perhaps 0.5 m, above Datum. A transgression of that magnitude or less would tend to favour the alternative suggestion of Grant-Taylor and Rafter (1963) that extinction of *Xanthorrhoea* on Rottnest may have resulted from "desiccation during the Hypsithermal Maximum", corresponding to the warm Atlantic climatic phase of the northern hemisphere, which Wendland and Bryson (1974) locate between 8490 and 5060 yr ago.

Substantial quantities of rain-derived salt have accumulated in ground waters of lateritic profiles in the Darling Range and the adjacent wheat belt of south-western Australia. Studies by Dimmock *et al.* (1974) have shown that the concentration of this salt tends to increase sharply with lower rainfall and raised evaporation; the lowest salt concentrations occur in the more humid western areas, characterized by higher and more constant levels of stream discharge. Under the present climate on uncleared land in the Darling Range, salt discharge slightly exceeds input, according to Peck and Hurle (1973).

Clearly the net rate of salt accession has been greater in the past, and this build-up could be expected to occur in periods of lower rainfall and stream discharge associated with increased evaporation and concentration of ground water salt. If so, this phenomenon may be viewed as an index of past regional climate. It has been pointed out by Dimmock *et al.* (1974) that only a relatively brief period of time would be required to account for the large quantity of salt stored in ground water at Bakers Hill in the eastern Darling Range. The fossil evidence at Guildford suggests that the regional climate was much drier than present during the Middle Holocene, at least from 6700 yr BP until some time after 4500 yr BP. This dry period, beginning at some unknown time, may therefore have been the most recent episode of net salt accumulation in the ground waters of the Darling Range.

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Postscript.—An extension of the present fossil fauna has recently been discovered in core samples from the flood plain of the Swan near Guildford Grammar School, some 4.2 km upstream from the Helena confluence. It is associated with a black clay lying between 3 and 6 m below the ground surface. Molluscs are similar to the present assemblage; also present are echinoderm ossicles which represent an asteroid of the genus *Astropecten* (L. M. Marsh pers. comm.). The core samples, which are uncontaminated by the modern channel substrate of the Swan, do not contain the molluscs *Westralunio carteri, Xenostrobus securis, Anticorbula amara* and *Plotiopsis australis,* species excluded from the present study because of their association with the modern channel substrate at Guildford. The new material justifies this exclusion and supports the palaeoenvironmental deductions of this paper. Presentation of this new material by Messrs. H. Grant and J. Backhouse is gratefully acknowledged.

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